TOWARDS THE CHALLENGE OF BIODIVERSITY IN FORESTS AND FORESTRY

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Abstract

The UNCED Convention on Biodiversity commits governments to report regularly on the state of forest biodiversity. This includes the development of a system of indicators. For indicators to be useful they should constitute a feedback mechanism in the decision-making process. They should form a comprehensive and integrated system.

Much of the discussions on possible forestry indicators revolve around the identification of *species-based and system-based indicators*. The former category includes the use of endangered or flagship species as well as indicators of intraspecific variation. The latter category is intended to cover measures of forest structure and composition, the use of vegetation associations and ecological regionalizations, and measures of soil erosion or nutrient loss. From those two long lists of biodiversity indicators, a short list can be distilled, referring to the two major elements of the model framework, viz. *Drivers of Change and Attributes Inventoried and Monitored.*

Despite the general objective of forest biodiversity conservation, it is important to look closely at some of the current challenges that exists for the future in forest management. In summary, changes in forestry practices are heavily influenced by economic realities, particularly the supply/demands variables.

The shortage of information and knowledge implies that it will take time and effort and many iterative revisions to improve and refine the array of indicators that are required.

Keywords : forest biodiversity; biodiversity indicators

1. Introduction

Forests harbour thousands of species of plants, insects, worms, spiders, fungi, vertebrates and other taxa, including some direct economically important species. A forest may have dozens of easily recognised habitats and enfold numbers of physiological, behavioural, ecological and evolutionary processes (McKenny et al., 1994). In Canada some 71,000 micro-organisms, plants and animals, representing in total some 70 taxonomic phyla, are known and documented. This represents only about 5.1% of the 1.435 million described species of the world (McNeely et al.,1990). There is, however, still a tremendous number of unknown species. Estimations in Canada mention 150,000 unreported virus, 20,800 and 24,653 respectively unreported bacteria and insecta (against respectively 200, 2,400 and 29,913 reported species) (Mosquin and Whiting, 1992).

Due to tremendous disturbances of anthropogenic nature a **world-wide concern on biodiversity arose**, resulting in much activity in both science and politics. The essence of concern revolves around the impact of current economic activity on the planet's life support systems. Although much of the focus of public debate has been on biodiversity loss in the tropics, increasing attention is now being given to temperate, boreal and other ecological zones. At UNCED a Convention on Biodiversity was signed, stimulating signatories to develop national strategies, undertake studies assessing the status of biodiversity and processes impinging on its conservation and to collect, assess and make available relevant and reliable data in a form suitable for decision making at all levels.

This convention commits national governments to report regularly on the state of forest biodiversity. **This includes the development of a system of (national) indicators** to monitor and report on progress in achieving sustainable forest management. However, this is a complex matter for a variety of reasons, including scale, disturbance regimes and the influence of physical environment. It needs a long lasting and frank debate about the scientific merit, methodologies, difficulties, caveats and opportunities of such a set of indicators. **Much of the discussions revolves around the identification of species-based ver-**

sus system-based indicators. Some of the entries deal with very specific measures, whereas others involve the construction of broad suites of indicators, models or indicators. Anyway, there is some overlap both within and between the two lists. A general agreement, however, is growing stating there is really no difference between species management and ecosystem management.

Foresters, whether they like it or not, are involved in this debate. Forest biodiversity may and cannot be confined to biologists, as it is an extremely important instrument to achieve a sustainable forest management.

2. Values of biodiversity

One should be aware of the values associated with biological biodiversity, since its knowledge provides feedback to decision makers and the wider community on the impact of forest use.

2.1. What is biological diversity?

Because biodiversity is primarily a complex of finer-levelled issues, a simple definition is quite impossible. Therefore, authors dealing with the topic, either concentrate upon one of the many finer-levelled issues (e.g. species diversity, genetic diversity, landscape diversity), or attempt to define the range of types of biodiversity that occur (Noss, 1990).

Generally speaking, we know that biological diversity is much more than can be revealed by a count of species. It includes the complex pathways and processes that link organisms one to another and to the environment, their genetic composition, and the process that sustain the whole as dynamic, self-regulating systems (Kessler,1994). This point of view corresponds quite well with Ray's definition (1988) : biodiversity is the result of the interaction between biota, the physical environment, and the annual disturbance regime, in the absence of the impact of modern technological society. Such **fundamental definitions,** however, are not so good workable for foresters and therefore McNeely et al. (1990) proposed a **"working definition"** of biodiversity : the variety of life in all of its forms, levels and combinations, and including ecosystem diversity, species diversity and genetic diversity. The operating word in this definition is "variety" and the attendant implications on how it may be measured, estimated or valued, and then interpreted or applied for various purposes. A working definition should imply that biodiversity is not chiefly a scientific preoccupation, but that it also includes the consideration of a wide range of political, ethical, economic and social concerns.

World-wide attention was paid to the term in RIO 1992 and finally there seems to be agreement to accept the definition as formulated by the United Nations Conference on Environment and Development (UNCED) : **Biodiversity is the variability among living organisms from all sources including terrestrial, marine, and other aquatic ecosystems, and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.**

A definition of biodiversity supposes knowledge of the "baseline", what is, however, a complicated task. To conduct meaningful biodiversity monitoring, baseline data must be in existence. With regard to this Mackey et al.(1994) suggest for Canada's forests three potential baselines : the pre-First Nations, preindustrial and extant. Once the baseline is established, the impact of current human activities can be assessed. For example, one can ask what impacts modern forestry practices are having on the long term structure and function of certain forest types.

Anyway, biodiversity remains a complex item. It is much more than the distribution of numbers of taxa. Far more important are the functional interactions of organisms by dozens of ecological processes such as parasitism, nutrient transport, mineralization, fermentation and locomotion. In that perspective Salwasser (1993) designed the **linkages of functional interactions of ecological processes between the focal elements of biodiversity :**

1. Genetics : variation within and among populations.
2. Species/populatations : recovery, viability, productivity and sustainability.
3. Communities/ecosystems : structure, composition, functional processes.
4. Landscapes/regions : variety, biogeography, linkages, integrity.

The complexity of the challenge underlines the need for a better understanding and requires still huge amounts of additional research, performed on a interdisciplinary base.
Such efforts are justified because biodiversity conservation is a component of ecologically sustainable development. This is emphasised by Blamey and Common (1992), who state that the **planet's biodiversity serves at least four functions of interest to humans** :
- provides resources that are used in the production of goods and services;
- assimilates wastes that arising during both production and consumption;
- provides services that are directly consumed (these can be broadly defined to include amenity services, natural beauty and the maintenance of traditional cultures);
- provides the basis for the maintenance of ecosystem functions that support human life.

Next to these services, maintenance of biodiversity provides an underlying continuity to the evolutionary lineage of life on Earth (Mackey,1994).
The first four values are anthropocentric and therefore can be defined as economic in nature. They may involve direct uses such as timber harvesting or indirect uses such as the maintenance of watershed filtration functions. The fifth value represents the view that species other than humans have a right to exist and evolve.
With regard to these values it should be referred to the notion of sustainable biodiversity, defined by UNCED, as the development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

2.2. Components of biodiversity

A critical step is to define the different units of analysis. According to Thomas (1993) a three dimensional matrix can be used to characterise the **three main gradients that interact to define biodiversity for different "elements"** or components :
- biological scale : ranging from genes to biomes; we go from cell to organism to population to community to ecosystem to bioregime;
- geographic scale : from sites to region;
- temporal scale : from short term to long term.

Mackey et al.(1994) distinguish a **range of four spatial scales : site, regional, landscape and global scale**. They illustrate how the species and populations, community organisation and ecosystem processes, the physical environment, human impacts and natural disturbances can interact over a range of spatial scales. They thereby suggest the following :
- At increasingly finer scales, more factors can be incorporated to refine estimates of physical environmental processes.
- Species and population distributions can cross all scales.
- Biological patterns emerge at higher levels in the spatial hierarchy that are not apparent at lower levels.
- Ecosystem processes transcend all scales, depending a.o. upon the steepness of environmental variables.
- The ecological importance of disturbance depends upon the scala of community organisation being affected.

The obvious implication is that more than one unit of biological and spatial analysis is needed.

Discussions on biodiversity are mainly focused on two items, either species diversity or ecosystem diversity, the latter referring to community organisation and ecosystem processes.

2.2.1 Species diversity

Species diversity can be defined in terms of species richness, abundance/dominance and evenness and can be examined at different scales- so called alpha, beta and gamma diversity. Alpha is a measure of diversity within communities, beta measures the diversity between communities along some kind of environmental gradient and gamma measures diversity based on all communities within a geographic

region (McKenney, 1994).
Interpreting species diversity depends on knowledge of the systems total structure, composition and processes. Spatial and ecological context are needed to interpret the significance of species diversity. Various mechanisms have been proposed to account for the variation observed in species diversity, including disturbance/stability, predation and competition, productivity, physical environmental gradients and historic biogeography (McKenny,1994).

Predation theories predict that in some circumstances predation can promote diversity by reducing competitive exclusion.

Local diversity is higher where "productivity" is lower, owing to low population densities. However, the productivity theory of diversity presents an opposing viewpoint, where diversity increases with increasing net primary productivity. The difference between temperate and tropical systems has been used as evidence in support of this theory.

Regional species diversity can be related to the "slope" of physical environmental gradients. For example, if mesoclimate varies significantly over a relatively short horizontal distance, then regional species diversity can be expected to be high. Local adaptations to physical environment conditions represent an important component of biodiversity. All plants require energy, moisture and mineral nutrients. The spatial and temporal distributions and availability of these three primary environmental regimes (PERs) are therefore the major physical determinants of plant response.

At a broader scale still, species diversity can be related to geographic isolation and colonization. Most of boreal and temperate biomes were obliterated by ice sheets during the geologically recent Pleistocene series of ice ages. Most species have recolonised over the last 10,000 years. Hence, many ecosystem processes, such as those relating to soil development, are relatively youthful. There has therefore not been the time for geological and other events to occur and isolate populations, as there has been in the tropics.

Species diversity, however, **is mainly considered in association with disturbance regimes.** Various authors (e.g., Huston, 1979) have suggested that local diversity is maximised at intermediate levels of disturbance, as disturbance allows the maintenance of competitively inferior species.

Fire is a major source of disturbance in many forests. Fires kill some plants and create opportunities for others to grow. The fire regime therefore exerts a fundamental control on the special mosaics of forests' age structure. In Canada, on average, there are 7000-12000 reported forest fires each year.(Canadian Pulp and Paper Association, 1992). Normally the area burned approximately equals the area harvested. In 1989, however, a particularly bad fire year, 7.5 million hectares burned, which is the equivalent to about eight times the average annual harvest level. Fire is a natural part of the ecological cycle in many forests and typically controls and characterises the natural patterns of landscape diversity. Fire suppression changes the nature of the forest age structure and tree composition over time. According to Ward and Tithecott (1993) the average turnover in Ontario is now 578 years, in contrast to the turnover of 65 years before it was started to suppress fires.

Insect infestations (budworms, caterpillars) and fungi that attack the root systems of trees occur in vast numbers and over large forest areas. As a result timber losses occur, which in Canada are approximately equal to the area harvested (Forestry Canada,1992). Most pests follow standard oscillations and infestation patterns and, in spite of research, the majority of suppression and control attempts are, in the longer run, unsuccessful (Sims,1994). Insects and fungi are classed by many as undesirable disturbances. The opposing and increasingly accepted view, mainly by biologists, is that they play an integral role in nutrient and carbon cycling within a forest ecosystem.
The impact of human forestry practices is a source of much controversy. In the context of forestry, it is often stated that timber harvesting mimics the disturbance effects of fires. However, fires burn more heterogeneously than timber harvesting and they often leave behind more plant material and hence nutrients. When we compare the spatial and temporal patterns of current cutting, we also immediately rec-

ognise that our cut patches are relatively small compared with fire damage and, as mentioned above, it is apparent that modern society has changed the natural fire regime. Besides, critical questions are the extent to which human land use practices are affecting population viability, species distributions, vegetation associations, forest age structures and ecosystem structures. **Much discussion has always been focused on the minimum manageable area, clearcut practices and harvesting equipment.** Various forms of clearcuts, including block, strip and large pattern cuts, still account for major parts of harvesting in large areas of boreal regions, whereas selection cuts or other alternative and less invasive forms of harvest are more widespread in Central-European areas and are contemporary strongly promoted by the close to nature forestry movement. Sims (1994) points out that in Canada the minimum manageable area for forest practices has traditionally been 40 acres (about 16 ha), but that today this area is generally considered to be about 8 ha, so there has already been some shrinking. He hopes, however, that, instead of harvesting 1 million hectares annually, there should be harvested 1 million 1- ha blocks, of which, admittedly, many are contiguous.

2.2.1.1 Intraspecies diversity

In connection with species diversity, it must also be referred to intraspecies or genetic diversity. This aspect is due to local adaptations and is **closely related to spatial gradients in physical environmental regimes. The result is the existence of ecotypes or populations.** The greater the environmental difference between the habitats of populations and the longer the time passed since these populations dispersed, the greater is the potential for genetic variation as a result of local adaptations.
Genetic variation is often viewed as a fine-scale level of biodiversity. But Joyce,1994, states that this view ignores the complex structure and function of genetic variation at the ecosystem, species and population levels. He views genetic variation more appropriately as an attribute of biodiversity, rather than a scale. As such, it is one of the primary resources requiring management.
Generally speaking, **there is a wide genetic adaptation by many species,** which show broad ecological amplitudes and huge geographic ranges (Mosquin and Whiting,1992). The occurrence of these phenomena is highly valuated by **Ledig** (1993), who **considers the loss of populations as perhaps the greatest threat of biodiversity** and speaks of the "great unseen wave of extinctions". In this respect, the fragmentation of the forest, due to agriculture and urbanisation, should also be mentioned. As a result, the genetic integrity of species and populations is suspect.
Mackey (1994) concludes, that every (noncloned) organism has a unique genetic blueprint. In terms of genetic dimensions, a population can be expected to be to some degree distinct from every other population of that species. In some circumstances, therefore, populations rather than species may be a more appropriate biological unit of analysis for the conservation of biodiversity.

2.2.1.2 Rare and endangered species

Special attention should also be given to rare and endangered species, as **public concern over the loss of biodiversity is often expressed in terms of the need to protect rare and endangered species**. It explains why, with an increasing frequency, special legislation is enacted to protect such species.

Rabinowitz et al. (1986) suggested that there are three dimensions to rarity :

- the geographic range of the species;
- the habitat specificity of the species;
- the size of the local population.

It is evident that the definition of rarity demands a spatial context. The degree to which a species is endangered or vulnerable to extinction is very much determined by the spatial context and the relationships between range, population size, the impact of land use change, habitat and habitat quality. It is also useful to make the distinction between global and local extinctions. Global extinctions of "flagship" species (e.g. whales) often attract widespread and public concern. Unfortunately, local extinctions are usually overlooked (Ledig,1993).

2.2.2. Ecosystem diversity

Next to species diversity and in certain contrast with it, **ecosystem diversity is a major component of biodiversity. Populations co-occur in space and time and thereby form biotic communities, featured by community organisation and ecosystem processes.** Community organisation is essential for both the presence of certain species and the maintenance of ecosystem functions. The notion of ecosystem stability and resilience stems from the fact that ecosystem processes persist even though individuals and populations may come and go (Holling, 1992). These processes are the result of community organisation. At a landscape scale, two of the most important processes are the water and nutrient cycles. These involve complex interactions between plants, animals, climate, terrain and the substrate. For example, soil microflora represent an important component of biodiversity in terms of both the number of species and the roles they play in forest ecosystem processes. Chanway (1993) suggested that the maintenance of mycorrhizal diversity below the ground is necessary to ensure the biodiversity of the aboveground vegetation.

The ecosystem approach leads to the popular idea of "ecosystem management". There is, however, no real agreement on the meaning and definition of this concept. Soulé (1994) distinguishes at least five ecosystem approaches or goals of ecosystem management :

- protection of the entire range of ecosystem types;
- protection of ecosystem services for human welfare;
- protection of ecosystem processes, including the continuation of natural disturbance regimes;
- protection of ecosystem health or integrity;
- protection of the balance between human economic needs and biodiversity conservation.

The latter is the definition favoured by UNESCO's Man and Biosphere Program and by many Forest Services.

2.2.3. Conflict between species based and ecosystem based approach

Nice discussions were developed in the past between supporters and opponents of the species based and system based approaches, inclining to a priority of ecosystem approaches. The science of ecology was split for decades between population-community ecologists and ecosystem ecologists.

The question could be formulated as follows : **how much importance should be given to community organisation?** Johnson and Mayeux (1992) proposed that the physiognomic structure (vertical and horizontal) of the vegetation is in the long term more important to ecosystem stability and resilience than taxonomic composition per se. They suggested that species have been added to or removed from ecosystems in many contexts without greatly affecting ecosystem function.

In terms of plant associations, Mackey et al. (1994) identify both weak and strong positions. A weak position might argue, for example, that vegetation associations are largely fortuitous. This viewpoint would indicate that no great effort is required to preserve existing associations. A strong position would suggest that there are overriding biotic interdependencies and that communities have a well-developed internal organisation. The effects of canopy shading on regeneration, microclimate and soil moisture, for example, are indicative of processes that stem from, and are part of, the process of community organisation.

The conflict mainly arose between conservation biologists and resource managers. For the latter, the good can be defined as that which serves the higher needs of human society. In contrast the former believe that the world is larger and more important than humanity alone.

Soulé (1994) concludes that critics have attacked species -based approaches because the laws have not succeeded in bringing many species back from the brink, because agency biologists have devoted all of their efforts to making more white-tailed deer, ducks and trout and because such approaches do not prevent species (and ecosystem) from becoming vulnerable to extirpation. He summarises **the fundamental criticism of the species approach to conservation** as follows:

1. It cannot, by itself, justify a comprehensive network of protected areas that ensure the survival of examples of all the world's biotic communities.
2. It may not address ecosystem services and maintain ecosystem functions.

3. It may ignore issues of reserve design : shape, size, scale and connectivity.
4. It may not incorporate all elements of diversity, such as biotic gradients and habitat mosaics.
5. It may ignore the dynamics of disturbance regimes.
6. It may not consider long-term global change.
7. It may not be cost-effective.
8. Endangered species legislation is failing to stem the rising tide of candidate species. In addition, it focuses on too narrow a range of species, primarily large vertebrate, commercial and sport species, often to the exclusion of plants, invertebrates and sensitive species, or species that may act as indicators of environmental health.

There is clearly no simple interpretation to species diversity. Its significance can be evaluated only in the context of a specified space/time scale, and only where the relative roles played by disturbance, predation/competition, environmental gradients, heterogeneity and productivity are clearly understood (Mackey et al.,1994).
On the other hand Soulé (1994) underlines also scientific/conceptual and practical **problems with the ecosystem management approach :**

1. A universally acceptable classification scheme for biodiversity does not exist.
2. Ecosystem management leaves unanswered the critical question : how much of each ecosystem is necessary, how big an area do we need?
3. The intention to ensure the continuation of ecosystem processes and natural disturbances regimes is excellent. In practice, however, a process approach can be perverted and oversimplified, resulting in significant losses. For instance, a persistent myth in forestry is that increasing the diversity of habitats is beneficial to wildlife. Foresters often say that logging benefits wildlife, but logging, although it is beneficial for certain species such as deer, is harmful to many others, including those that require nearly undisturbed, interior forest and those that require complex vertical and horizontal structure.
4. Concepts like health, integrity and resilience are difficult to define and operationalize. We must ask the popularizers of these concepts to quantify and to set thresholds of acceptability.
5. Ecosystem management is often equated with the concepts of sustainability and harmony, ignoring, however, the growth of human populations.

To overcome these problems, forestry adopted, already decades ago, **the multiple-use philosophy**. Soulé (1994) stresses, however, that is is now clear that this approach has often caused the overexploitation and simplification of biotic communities. According to him it is absurd to think that adding an additional use for forests (the protection of biodiversity), while not eliminating or reducing the intensity of extractive uses, is a viable policy. His objective is to emphasise the **need for a synthetic approach that incorporates all ecosystem management goals along with species-based approaches**. The essential point is that the dualism of organism and environment is a dangerous blasphemy against ecology.

3. Biodiversity indicators for forests

People want to know how our forests are doing. But how can we measure that and encompass all entities, species, communities, habitats and services? We want even to know about the behaviour of the people using the forest. What are the immediate and long-term consequences of their activities?
We cannot, howver, measure everything. Instead, we have to select a few variables that we believe represent the life of the forest. **These representative elements and processes are indicators. Indicators are variables that we choose to monitor.** They reflect our values (what is important) and our pragmatism (what is feasible?) (McKenney et al.,1994). Monitoring these indicators would form a basis for periodic reporting on the state of forest biodiversity.
The need for a system of biodiversity is underscored by the important role of forest products in the national economies of many countries, the likelihood of increasing national and international demand for wood products, trends in extraction technologies and a potentially conflicting call for overall planning for long-term sustainability (Soulé,1994).

It is, however, generally recognised that **the problem of achieving a set of (national) biodiversity indicators is formidable.** One reason for this is the inherent complexity of ecosystem/landscape phenom-

ena and their dynamics. Although many experts agree that hierarchical models and attention to scale help to classify and communicate about genes, populations, species, associations and ecosystems, it is also appreciated that many phenomena transcend spatial boundaries and sometimes confound attempts to categorise and simplify.
To conduct meaningful biodiversity monitoring, baseline data must be in existence. Indeed, we often do not know the "normal" number, or even if the concept of normality applies. In such a case the data for the first few years of monitoring constitute an inventory of what is present. With certain caveats, these census inventories can serve as baseline for monitoring future changes.

3.1. Options for biodiversity indicators

The development of a comprehensive set of useful biodiversity indicators involves an understanding and synthesis of many complicated scientific issues. **For indicators to be useful, they should constitute a feedback mechanism in the decision-making process.** There needs to be a link between the observed change in biodiversity and the causal agent. This information can then be used by resource managers, other decision makers and the public.

The attributes we measure must meet basic criteria for scientific measurement, reflect human values of what is important and be selected to give maximum warning of developing problems (Welsh, 1994; Kessler, 1994).

Sims and Addison (1994) point out that, **to identify biodiversity indicators, we first need to undertake the following steps** :
- determine the kinds and numbers of indicators that are required, including direct, indirect, surrogate and compound indicators;
- clarify and document the elements of biodiversity that those indicators will represent or measure;
- identify the tolerances and ranges of variability that would be required or accepted around each of these indicators;
- demonstrate the nature and dimension of any "random effects" that may arise in measurement or estimation of any indicator.

Mackey et al.(1994) **distinguish two sets of indicators. Indices will be required that operate at a selection of space/time scales** : e.g. the diversity and abundance of ground cover species in a landscape can be sampled using a network of ~100-m² plots; the distribution of patches of forest types requires fine-grained analysis but over an entire landscape of, say, 900 km²; analysis of songbird habitat requirements may require the collection and analysis of some detailed observations over 3-5 years or longer from 1-km² plots scattered over an entire region.
A second set of indicators would be needed to describe the extent to which anthropogenic activities are (or are not) resulting in biological impoverishment. There would be a subset of indices that could be used both to characterize biodiversity and to monitor change through time.

In addition to scientific considerations the **availability of data, cost of measurement and ease of application must also be considered in selecting biodiversity indicators.**

The tyranny of small decisions(Kahn,1966), referring to the "billions of independent decisions" (Perrings et al.), confounds the development of meaningful indicators . Independently, each decision likely has an insignificant impact. In total, however, the effects may be significant. This leads to the **topic of threshold values, i.e., how do we determine that an impact on biodiversity is significant?** The determination of threshold values will clearly becomes the focus of public debate. What is required, however, are measures of the cumulative impact of mutually independent actions.

Taking in mind a lot of considerations, McKenney et al.(1994) formulate several **guidelines for the selection of indicators** :

- the selected indicators should be relatively easy to monitor;

- the monitoring should pass the test of good experimental design;
- the monitoring should do more good than harm;
- avoid fads;
- indicators should monitor processes and flows as well as states and stocks;
- indicators should provide early warnings before it is too late to reverse the deterioration;
- some indicators should be dramatic, for example "flagship" species such as the wolf;
- some indicators should be "umbrella" species, such as grizzlies and eagles, that requires large areas to maintain population viability;
- the list of indicators should include targets from all the relevant ecological scales and levels of biodiversity;
- the monitoring of chosen indicators should be an inherent component of an integrated, long-range master plan;
- the objective should be clear to everyone.

In addition to these guidelines, Soulé (1994) emphasises the **requirements, that surveys and monitoring** :
- provide better information about the genetic diversity of trees;
- produce better information on the geographic distributions of species;
- reflect overall system health, viability and function;
- incorporate the benefits of species- and system-based approaches;
- provide "early warning" services;
- be useful for predicting future trends;
- use standardised methods.

3.2 Framework for the development of indicators

When tackling a complex issue, it is useful to develop a framework or model that simplifies the components and helps to clarify their interrelationships.

Discussing the options for biodiversity indicators Mackey et al.(1994) **distinguish four units of analysis or indices.**

3.2.1 Units of analysis based on species

Species diversity indices (SDIs) are based on quantitative measures of species richness, abundance/dominance and evenness. Because it is not feasible to comprehensively study all populations of all species, one have to confine the monitoring to "indicator species", using various criteria, such as :
- economically and culturally important species;
- guild representatives (e.g. one species to represent a number of ground-breeding migratory forest songbirds);
- top-of-the-food-chain-species;
- species with large home ranges;
- flagship species (species with popular appeal);
- keystone species (species that play a critical role in the maintenance of ecosystem processes) ;
- rare, threatened and endangered species.

Although the high practical value of indicator species, Landres et al.(1988) formulate strong arguments against them : each taxon has its own unique set of biophysical requirements and responses; predators may be dependent upon prey, but the reverse is not true; there is a current lack of autecological and synecological knowledge; species can come and go, yet ecosystem services can still be maintained. Nonetheless, much of the public discussion on biodiversity conservation has focused on indicator species, in particular rare or endangered species or commercially important species.

3.2.2 Units of analysis based on intraspecific diversity

It is possible to examine, on a species-by-species basis, the extent to which populations can be distinguished owing to local adaptations. If local variations are significant, then the results could be used to identify populations that warrant conservation. The question, however, is : how can genetic diversity measures be interpreted? For example, to what extent does the difference between populations in genetic diversity per se constitute a component of diversity that should be conserved?

3.2.3 Units of analysis based on community organisation and ecosystem processes

Perhaps the simplest way to capture this component of diversity
is to focus on extant patterns of biotic associations, using a variety of criteria, including :
- plant floristic associations;
- vegetation physiognomic structure;
- potential habitats of indicator species or guilds.

Such analyses would be suitable for the establishment of protected reserves. In this respect it can be reminded that many government support the notion that 12% of the Earths terrestrial systems should be protected within a reserve network, to serve for the maintenance of broader-scaled patterns and processes. But, even if 12% of land is reserved, it can be argued that the conservation of biodiversity will be affected more by what happens outside reserve networks than by what happens within.

3.2.4 Indices of disturbance and change

As explained by Hopkins (1990), the disturbance regime is multidimensional and can be defined in terms of intensity, duration, frequency, extent, and the causal agent. As all these variables effect the ecological impact of a disturbance on biodiversity, it is even complicated to obtain spatial information about extant disturbance regimes.

Welsh (1994) on his side underlines that **our biological framework needs to contain three elements :**
- an accurate, ideally spatial, description of the present attributes of the system, including both structure and function (what is the present forest like?);
- a monitoring system to measure how the system changes over time;
- a good set of expectations for what should happen over time, based on models and the study of undisturbed areas.

As a result of a Canadian workshop, McKenney et al. (1994) developed a framework that identified major components of a biodiversity indicators system. **The two major elements of the model are *Drivers of Change*** and ***Attributes Inventoried and Monitored*** (Fig.1).

The framework includes, as a central theme, the temporal and spatial components upon which biodiversity must be measured and understood. Operating upon these two gradients are outside forces that effect change. **Drivers of change essentially refer to management actions, such as land logged, road development, harvest levels and regeneration effects.** There are two distinct categories of these system drivers, viz. natural effects and anthropogenic effects.

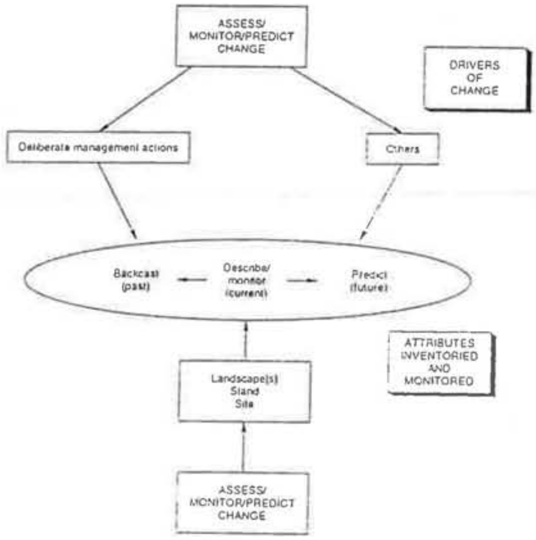

Figure 1: *Framework for biodiversity indicators (McKenney et al. 1994)*

The former are ecological processes that occur within or to forest ecosystems, whereas the latter include factors such as climate change, pollution and other stressors. **Attributes inventoried are the intended and unintended consequences of management actions on biodiversity at the site, stand and landscape levels.** The temporal gradient moves from past to present to future.

3.3 Possible forest biodiversity indicators

Biodiversity indicators are required to provide feedback to decision makers and the wider community on the impact of land use and resource utilisation.
Indicators should form a comprehensive and integrated system. It would be inefficient and wasteful if some units monitored only insects and others monitored only nutrient dynamics (Soulé,1994).
According to Hamilton (1994) **the components of the monitoring system include drivers or agents of change and response variables**. Some of the system drivers are directly linked with forestry activities, whereas others are more indirectly related.

The direct drivers include :
- the spatial extent of logged land (by ecological area) and of roads (type, density, effect on wilderness quality);
- the frequency and spatial extent of fire and insect and disease outbreaks;
- the spatial extent of productive forest land (by ecological area);
- the forest harvest level (by ecological area);
- conversion of riparian and wetland habitats;
- number of exotic species;
- extent of reforestation and area protected (by ecological area).

Attributes of response variables are :
- measures of water quality and quantity;
- changes in soil productivity;
- measures of climatic change;

- measures of stress (e.g. pollutants - acidic deposition and toxins in wildlife).

A status of information on species presence and population levels should be available. Today, the distribution of bird species, particularly game birds, diurnal birds of prey, and water birds, and large mammals, particularly game species, is generally better known than is the distribution of other vertebrates and invertebrates. Distributions of amphibians, reptiles, and bars,. shrews, moles and other small mammals are poorly known. Vascular plant species distributions are better known than are those of non-vascular plants, fungi and lichens. Information on distributions of invertebrates and fungi, except for those of commercial importance (e.g. forest pests), is fragmentary to non-existent (Ryan et al., 1993; Gordon and Hamilton, 1994). With regard to indirect drivers, only a limited number of data, e.g. on water and air quality, climatic conditions and levels on toxins in wildlife) are available.

Much of the discussions on possible forestry biodiversity indicators revolve around the identification of species-based and system-based indicators. The species based category includes the use of endangered or flagship species as well as indicators of intraspecies genetic variation. The system-based category is intended to cover measures of forest structure and composition, the use of vegetation associations and ecological regionalisations, and measures of soil erosion or nutrient loss.

The Canadian workshop on forest biodiversity indicators generated two 'long-lists' of species-based and respectively system-based indicators (Tables 1 and 2; McKenney et al.,1994).

Table 1: *Species-based indicators*

- spatially distributed habitat suitability models for rare, threatened, endangered and vulnerable species, including the monitoring of change;
- spatial distribution of habitat specialists;
- annual updates of rare, threatened, endangered and vulnerable species lists;
- adding non-vascular plants (e.g. fungi) to lists of rare, threatened, endangered and vulnerable species;
- in-depth measures of selected rare, threatened, endangered and vulnerable species;
- degree of population fragmentation and size of selected species;
- monitoring medium-sized to large carnivore populations;
- measures of relative abundance of all bird species spatially and by habitat type;
- definitions of appropriate guilds and the determination of guild representativity in given landscapes;
- harvest levels of fish and wildlife;
- measures of habitats disturbed by beavers;
- measures of insect guilds related to forests but not restricted to commercially important pests;
- annual updates of new species per year and per geographic area;
- measures of extant vegetation and disturbance regimes;
- measures of environmental space (niche) and geographic space occupied by organisms;
- identification and monitoring of lichen species specific to old-growth forests;
- measures of below-ground species diversity, including numbers and abundances by ecosystem type;
- changes in tree species by forest cover type and/or ecosystem type over time;
- proportion of tree species that have a gene conservation strategy in place;
- measure in situ and ex situ genetic conservation strategy of tree species;
- measuring/monitoring taxa that perform an integration function (e.g., amphibians, salmonids, new tropical migrants, nocturnal moths, forest floor beetles);
- absolute population levels (estimates) of selected species guilds;
- measures of genetic diversity of forest populations;
- measures of stress in populations/species;
- changes in vegetation/species distributions on private land;
- toxic compound levels in wildlife.

Table 2: System-based indicators

- access vs. non-access roads, including type and density;
- use of access as an indicator of 'wildness' quality
- fire disturbance : are burned frequency and amplitudes of fire;
- insect disturbance : area impacted frequency and amplitudes of outbreaks;
- number and percentage of exotic species;
- changes in forest cover (type, age class) within bio-region or ecosystem type;
- changes in harvesting systems, including adoption of new technology;
- trends in size of clearcuts;
- regeneration success of harvested areas inclusive of vertical structure and composition;
- spatial extent of different age classes;
- harvest levels as proportions of primary productivity;
- representativity of ecosystems protected and measures of protected lands;
- indices of landscape composition heterogeneity and configuration;
- changes over time of ecosystem processes (e.g. decomposition);
- measures of connectivity between protected spaces; degree of isolation;
- measures of water quality and flow regimes (e.g. chemistry, physics, organics, temperature);
- energy consumption levels in ecosystems;
- measures of climate change;
- measures of non-biotic rarity;
- use of growth and yield data to measure site quality and change over time;
- measures of plant vigour;
- adherence to acceptable forest management practices;
- public expenditure on spatially related research and development and forest management;
- levels of pollutant leadings within ecosystems (e.g. acidic deposition);
- trends in deforested riparian habitats and changes over time to wetlands;
- land alienation (e.g. flooding);
- measures of below-ground structure and function (e.g. soil microflora and microfauna, mycorrhiza);
- changes in soil productivity;
- measures of structural components at risk (e.g. snags, logs);
- areal extent of habitat at risk for selected guilds;
- measures of diversification in forest-based livelihood;
- measures of robustness of ecosystems to absorb impact;
- national policy decisions and effects on biodiversity of other countries;
- measures of government policies that run counter to biodiversity conservation;
- measures of national biodiversity relative to other countries;
- recreational usage of forests and effects on biodiversity

These lists summarise all kind of items, which are not prioritised, nor do all of them represent practical or 'do-able' indicators. Some of the entries deal with very specific measures, whereas others involve the construction of broad suites of indicators, models or data bases. Some of the indicators clearly require a great deal of thought and in some cases considerable additional research and development to implement .

Because such long-lists are not practicable, the participants of that Canadian workshop finally agreed upon a **short list of possible indicators** (table 3) based on considerations of :

- the significance/value;
- general impressions on practicability;
- the scale of the indicator (national, regional, local);
- the degree to which the indicator could be used as a predictive as well as a descriptive tool.

This short list contains the two major elements of the model framework, i.e. Drivers of Changes and Attributes Inventoried and Monitored (see Fig.1).

Table 3: *Short list of biodiversity indicators*

Drivers

- area logged and harvest levels summarised by regions or ecological area;
- roaded land, including type, density and effect on wilderness quality;
- measures of fire and insect disturbance regimes, including area, frequency and amplitudes;
- policy disincentives;
- measures of climate change;
- measures of water quality and flows;
- changes in soil productivity;
- measures of stress, including pollutants (e.g. acidic deposition, toxic compounds in wildlife).

Attributes Inventoried and Monitored

- indicators for forest trees (genetic diversity, changes in vegetation on private lands, harvest levels by species, etc.);
- indicators for other taxa, including carnivores, amphibians, lichens and non-commercial tree and plant species (determining population levels, describing trends and shifts over time, etc.) by bio-region or ecological area;
- indicators for rare, threatened, endangered and vulnerable species (e.g. annual updates of lists);
- patch and landscape measures of composition, structure and configuration.

Species can be used as indicators in at least three ways. First, a species can be used as indicator where the objective is to ensure the preservation of that species. Second, the species can be used as a surrogate for other species with correlated life histories or habitat requirements. Third, a species can be used to assay the condition of the forest system. In terms of the accepted classification, the first and second are species-based, whereas the third is system-based (Mackey et al.,1994). Like many classifications, there is considerable overlap.

Kessler (1994) emphasises, that **biological diversity is much more than can be revealed by a count of species**. It includes the complex pathways and processes that link organisms one to another and to the environment, their genetic composition and the processes that sustain the whole as dynamic, self regulating systems. He means, that by developing indicators for conserving biological diversity, we need to expand our traditional focus on species to the ecosystem level and landscape scale. Nevertheless there are some very important reasons why we must continue to focus on species. One is that society genuinely values some species more than others and demands that we invest public and private resources accordingly in assuring their survival. But we all know that the species approach is insufficient as a conservation strategy for biological diversity. The sheer number of species makes that impossible; we could never focus attention on them all. Many of them are simply not accessible for study; for example, the vast assemblages of organisms that live below the ground.

4. Discussion

Biodiversity has today national attention. In most countries it is a political issue. But let there be no misunderstanding : biodiversity is not the goal, it is the conservation of biological resources.
The development of biodiversity indicators is a primary need. Basic information on some of these indicators is already available, but an amount of work is still remaining to further develop them. First, it is necessary to establish patterns and relationships and then indicators can be developed. Although there is a certain desire for a single environmental indicator at the national level, a compilation of a minimum number of interactive and comprehensive indicators is an absolute requirement. To remain workable, the target number might be fixed at 8-10 representative indicators.

The present experience on this complicated matter allows to formulate some **general recommendations towards biodiversity conservation** (McKenney et al.,1994):

- There is a need to identify the "starting point" or the "temporal baseline".
- (National) biological inventories should be strengthened.
- Long-term ecological research should be intensified, particularly in the areas of composition, structure and function.
- Biodiversity conservation needs to be incorporated into both shorter- and longer-term resource management plans.
- There should be stronger support for multidisciplinary scientific research programs on biodiversity.
- Computer modelling must be a critical part of the way we address biodiversity conservation between species and ecosystems.
- Scientists have a responsibility to continue to work towards scientifically based knowledge and trend away from intuitive approaches.
- Existing data, such as forest insect and disease survey's ,should be used more efficiently.
- Digital mapping, spatial referencing of data, automated cartography and visual output of results should be used more frequently.
- A major challenge for biodiversity conservation involves the appropriate management and communication of scientific information.
- A visual aspect to an indicator is a useful attribute and this mechanism should be used to help convey the information provided by such indicators.
- The development of forestry biodiversity indicators must not be done in isolation from other resource sectors and other ecosystem conditions.
- The development of indicators is not something that can be done casually. Before specific indicators are finally selected, there will likely be a need for a series of workshops.

Despite the overall objective of forest biodiversity conservation, it is important to look closely at **some of the current challenges that exist for the future in forest management.** In that respect Sims and Addison (1994) suggest the following points of potential sources of frustration :

1. International market pressures will dictate the demands for forest products. The current prediction is a 2% per year growth world-wide for forest products.
2. Forest mill requirements will dictate the species mixes and the harvesting pressures "of the day". Consequently, they well be a key determinant of where management practices must be focused.
3. Forest practices in the bush will always be dictated by the equipment that is available and the regulations affecting its use.
4. Non-timber, multiple-use components of forestry will become more effective drivers of planning (and therefore change) as more is learned about their value compared with wood costs.
5. Pressures from governments, labour, competitors and the general public will force forest industries to continue to assume direct control and responsibility for forest operations. There will be increasingly restrictive government regulations that direct the forest industry to bear more of the responsibility for all phases of forest management planning, forest land rehabilitattions and forest development.
6. Forest practices and forest management planning will continue to represent two distinct "camps"; silviculture and other activities will continue to lag well behind projected needs and desirable levels. "We will always know how to manage better than we will be able to".
7. Ecological/environmental pressures are a wildcard, because public opinions can cause a chain reaction in the six points described above, simply by altering the demands for forest products.

In summary, changes in forestry practices are heavily influenced by economic realities, particularly the supply/demands variables. Therefore Sims and Addison (1994) conclude that, in developing biodiversity indicators, there is a need to be careful because there is a "moving target" involved. Any set of indicators based upon current (or past) concerns/problems will need to be very resilient if it is to address conditions that exist in the future. From the scientific point of view, **there is a need for a better understanding of :**

- successional pathways;
- wildlife behaviour and response to disturbance regimes;
- long-term versus short-term ecological effects of disturbance regimes;
- physiological and symbiotic relationships of trees;

- all below-ground interactions, functions and processes;
- carbon cycle components over time, especially in relation to disturbance regimes;
- global effects (forest health, climate modifications, etc.) ;
- valuation of non-timber features.

The shortage of information and knowledge implies that it will take time and effort, and many iterative revisions, to improve and refine the array of indicators that are required.

With respect **to the development of biodiversity indicators** for the Canadian forests, McKenney et al.(1994) concluded with the **following recommendations** :
- The development of indicators requires a clear articulation of the spatial scales involved.
- Because the development of a comprehensive list of biodiversity indicators is complex, the process requires that there be representation of the net effects of intricate, detailed interactions of biological organisms across a spectrum of geographic and ecological conditions.
- Defining suitable indicators requires that specific hypotheses be clearly articulated. There should be an accepted "standard" of what represents essentially a pristine, healthy, desirable condition.
- Indicators should be constructed such that they can be related to alternative management scenarios.
- At the overview level, there is a requirement to identify perhaps only 8-10 indicators that can be used to generally describe and represent the "overall biodiversity state of the forests".
- There should be a strong emphasis on further research and development in the use of spatial analysis tools such as GIS and remotely sensed data.
- Formal sets of recommendations need to be developed, that describe how to collect, record and present various data types and data elements that have biodiversity indicator value.
- A nontrivial issue is to determine the time periods that will be required to update forest biodiversity indicators. Biodiversity indicators are not costless.
- Efforts should be made to involve and utilise the public and volunteer organisations in data collection and monitoring programs.
- The development of some biodiversity indicators should occur in pilot studies- i.e. within distinct geographic areas.
- More attention needs to be given to genetic biodiversity issues.
- There is a need to acquire better information on the ecological requirements and autecology/synecology of intraspecies relationships.
- There is a fundamental need to examine the total geographic and ecological distribution of an organism if it is to be fully understood for the purposes of using it as an indicator of biodiversity.
- There is a need to go beyond purely species-based indicators.
  A complementary set of measurements is required to describe overall system health, viability, processes and dynamics.

It is important to be aware of the limitations in using a given indicator and of the potential for misinterpretation. The complexity of the subject also demonstrates that certain issues are unlikely to be resolved in the short term. Categorising indicators into either species- or system-based groups provides a convenient theme for structuring discussion on indicators. Some type of baseline must be established against which change can be measured (Mackey et al.,1994).
Biodiversity monitoring is problematic because of the breadth of the topic. It spans scales from genetic to landscape, with each scale requiring a completely different set of tools and expertise. Within each of these levels, the questions are large and complex, and often our understanding falls short of that needed even to identify appropriate measures. **While we conduct the research needed to make informed choices of indicators of biodiversity at the various scales, we cannot afford to wait for the answers, but we must measure those things that make sense, adding or dropping measures as better information becomes available** (Loo, 1994).

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